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The influence of the construction method on the behaviour of geosynthetic reinforced walls – A numerical study

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ABSTRACT: The role of the constrution method on the behaviour of geosynthetic reinforced walls is studied using an elasto-plastic 2D numerical model based on Finite Element Method. A propped reinforced wall and an incrementally built one are compared in terms of movements and tensile strains. The influence of props releasing sequence is also analysed.

1 INTRODUCTION

The construction methods of walls reinforced with geosynthetics can be basically two: incremental and propped. In incremental construction each level of soil and face is positioned more or less simultaneously and the reinforcements are tensioned for the first time during the execution of the overlying soil layer. In propped construction the wall is positioned propped, the soil is compacted at the back of the wall and the reinforcements are tensioned for the first time after the conclusion of the embankment when props are released.

In this paper the influence of the construction method on the behaviour of geosynthetic reinforced walls is studied by the numerical model described below considering one wall constructed incrementally and another propped.

2 DESCRIPTION OF THE CASE STUDY

An 6m height and 20m width symmetric embankment with vertical face and constructed over a competent foundation is considered in the study performed. The wall is reinforced with horizontal 4.8m long reinforcements, spaced 0.75m vertically, which are connected to the face. The inclusions consisted of uniaxial geogrids of high density poliethylene (TENSAR SR55).

The foundation and embankment soils are both supposed homogeneous and granular with the same mechanical characteristics. The soil subjacent to the foundation was considered indeformable.

The non-linear behaviour of the soils is simulated by a perfect elasto-plastic model with associate flow. The Mohr-Coulomb failure criteria was adopted. In Table 1 the mechanical characteristics of the soils adopted are shown.

Table 1. Mechanical characteristics of the soils

γ (kN/m^3)	K_0	ϕ (°)	c (kPa)	ν	E (kPa)
17	0.27	47	0	0.35	10000

The interfaces are simulated by a perfect elasto-plastic model with associate flow. Table 2 shows the mechanical properties of the soil-reinforcements and soil-face interfaces adopted in the study.

Table 2. Mechanical characteristics of the interfaces

	c_a (kPa)	tg δ	K_t (kPa/m)
Soil-inclusions	0	0.96	10000
Soil-face	0	0.61	2000

The behaviour of the inclusions is also simulated by a perfect elasto-plastic model with associate flow. The tensile strength of the uniaxial geogrids is 55kN/m.

The face deformability modulus considered was 5.5×10^5kPa for both wall types.

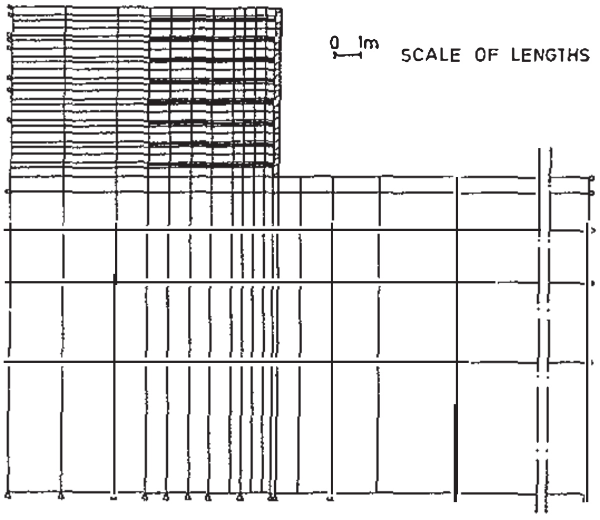

Figure 1 - Finite elements mesh.

3 NUMERICAL SIMULATION

The non-linear numerical model used is based on the Finite Elements Method and allows for the separate modelling of all the structural components. The soil and the face are simulated by 2D elements with five nodes (Doherty *et al.* 1969), the soil-face and soil-reinforcements interfaces by joint-elements with four nodes (Goodmann *et al.* 1968) and the reinforcements by bar-elements with two nodes.

Attending to the characteristics of the problem, initially the finite elements mesh includes only the foundation elements. The embankment soil, face, reinforcements and interfaces elements are introduced progressively in the step corresponding to its construction.

The finite elements mesh, shown in Figure 1, is initially composed by 100 finite elements, being 5 joint-elements; during the construction stages the 2D, joint and bar-elements representing respectively the embankment and the face, the interfaces and the reinforcements are introduced. In the last stage the finite element mesh has 580 elements, being 221 joint-elements and 72 bar-elements. The number of nodal points is 518.

The boundary conditions were established attending to the symmetry of the problem (left lateral boundary), to the supposed characteristics for the foundation (bottom boundary) and considering that away from a fixed distance to the face the foundation horizontal displacements can be considered null. This boundary was fixed at 40m from the face. The bottom boundary was supposed coincident with the top of an indeformable soil mass located under the foundation soil. For this reason the movements in this boundary were considered null.

The calculation of the initial state of stress follows the methodology described by Cardoso (1987).

4 CONSTRUCTION SIMULATION

The construction was simulated in accordance to the methodology described by Kulhawy (1977). In this methodology when a finite element is placed its self weight is divided by the element nodal points and applied to the system. During the process the deformability modulus of the placed elements is considered very small to simulate materials with weight but without stiffness. Before the construction of the next embankment layer, the deformability modulus of the last constructed soil layer returns to its real value; vertical stresses in this soil layer correspond to self weight and horizontal ones to the at rest stresses. The horizontal movements of the nodal points corresponding to that soil layer are considered to be equal to those of the top of the subjacent layer (Lopes 1992).

The incremental construction of the wall in 9 stages is simulated by considering, in each stage, the placement of one embankment layer and the start of tension in the reinforcement placed in the underlying soil layer.

During each soil layer construction the horizontal movements of the face at the reinforcement level are null; these movements become not null when the inclusion is tensioned. With this methodology the change in at rest state of stress is easily transferred to the reinforcements and thereby the correspondent tensile loads appear in the reinforcements. On the other hand, the face movements limitation simulates, in part at least, the effect of the supports currently used during the incremental construction of walls reinforced with geosynthetics.

The propped construction was modelled in the following way: (i) the embankment was constructed with null face movements in order to achieve the at rest state in earth stresses when it finishes; (ii) next, the props are gradually released in five increments (Caculation 2A, see Table 3), corresponding, each one, to an identical percentage of stress release along the face. The reinforcements are tensioned for the first time in the first increment.

For the propped wall it was also studied the influence of the sequence of props releasing (see Table 3).

Table 3. Sequence of props releasing.

Calculation	Props releasing
2A	Gradually in five steps
2B	In three steps: 1st the top third, 2nd the intermediate third and 3rd the bottom third
2C	In three steps in the reverse order of the Calculation 2B
2D	In one step

5 ANALYSIS OF RESULTS

5.1 Influence of construction method

The total horizontal displacements and the ones due to the reinforcements elongation of the propped (Calculation 2A) and of the incrementally constructed (Calculation 1) walls are presented in Figure 2.

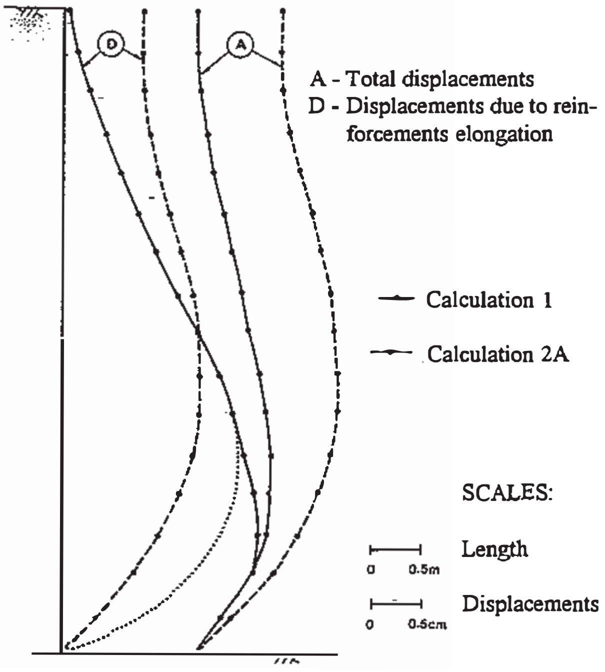

Figure 2 - Horizontal displacements at the end of construction (Calculations 1 and 2A).

The shape of total displacements are identical for both cases, but they are greater in the propped wall.

Comparing movements due to the elongation of the reinforcements, it can be said that their distribution is completely different for the two construction methods. In fact, the displacements are greater near the top for the propped wall, happening precisely the opposite for the incremental wall.

Being this part of total movements intimately related with the state of stress in the reinforcements, it can be expected greater strains in the reinforcements placed near the top for the propped wall and in the bottom for the incremental wall (see Figure 3). This behaviour is due to distinct soil stress paths for the two construction methods under consideration.

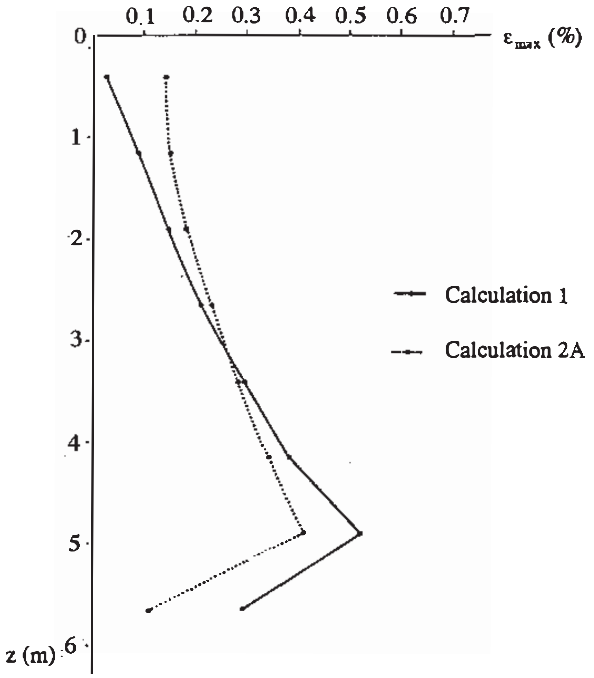

Figure 3 - Maximum reinforcement strains at the end of construction (Calculations 1 and 2A).

The efficiency of stress transference from soil to reinforcements is greater in the top and lesser in the bottom for propped walls than for incremental walls. So, in the first type of walls the soil stress level reduces near the top and increases near the bottom when compared to the second type.

It is worth noting that, due to its descontinuity, the deformability of an incremental wall face is usually greater than the propped wall face. Increasing deformability of the incremental wall face leads to an increase in the face movements and to an increase in the mobilized reinforcements strains. So, as the incremental wall face deformability increases the behaviour of propped and incremental walls became more similar near the top of the stucture and much more distinct in its inferior part.

5.2 Influence of the sequence of props releasing

In the previous section the props were gradually released in five increments, corresponding, each one, to an identical percentage of stress release along the face. This process allows the slow and gradual approach to the soil yelding. However, it has nothing to do with what happen in real structures. In fact, props are usually totally released following a sequence defined in the design.

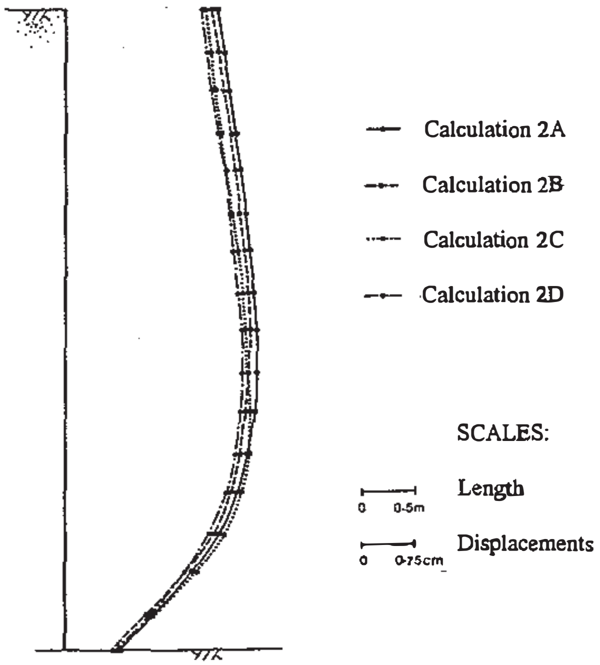

Figure 4 - Horizontal displacements at the end of construction (Calculations 2A, 2B, 2C and 2D).

In order to study the influence of sequence of the props release in the behaviour of propped walls three calculations were carried out with three distincts sequences of props release, all of them also different from that considered in Calculation 2A (see Table 3). In Calculation 2B it was supposed that props located in the top third of the wall were totally removed in the first step, followed, in the second step, by that located in the intermediate third and, in the third step, by that positioned in the bottom third. Calculation 2C is similar to Calculation 2B with an inverse sequence of props removal. In Calculation 2D all the props are removed in one increment.

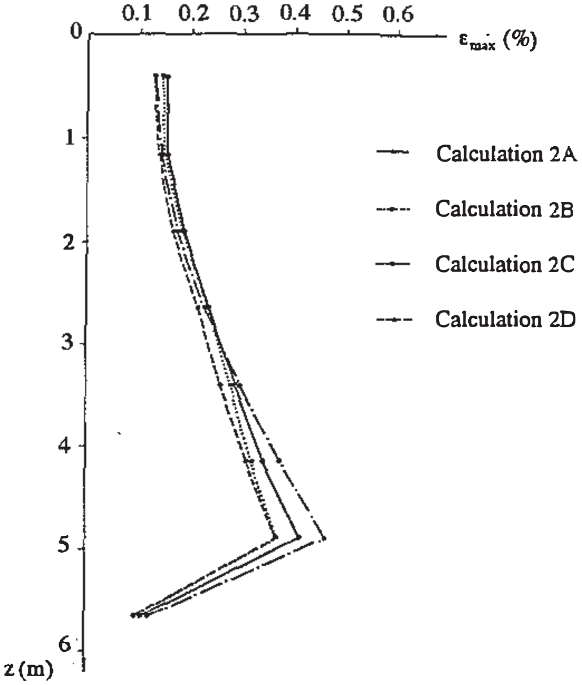

Figure 5 - Maximum reinforcement strains at the end of construction (Calculations 2A, 2B, 2C and 2D).

Figure 4 shows the total displacements of the face at the end of constrution for the four calculations. It can be observed that props releasing sequence has small influence in the total movements. The major differences, yet small, ocorred in Calculation 2D where the props are totally removed in one step; however, these differences may be more a consequence of the numerical modelling deficiencies of the non-linear behaviour than a consequence of real behaviour.

Comparing the displacements from Calculations 2B and 2C, it can be seen a very small increase in movements in the top third of the wall and also a very small reduction in the bottom third when the sequence of props release is from the top to the base of the wall (Calculation 2B).

Analysing maximum reinforcement strains (Figure 5), it can be said, as for face movements, that the influence of props release sequence is almost insignificant. The major differences are observed near the bottom of the wall, where the strains in the inclusions are greater. Comparing Calculation 2B (props releasing from the top to the base) with Calculation 2A, it can be observed a small reduction in the reinforcements strains. The contrary is observed when the sequence is inverse. This behaviour is due to a greater mobilization of shear stresses in the soil-inclusions interfaces located at lower levels when the sequence of props releasing starts in the base of the wall and to the fact that this reinforcements are the more tensioned ones. The inverse behaviour is observed in the top of the wall, however the evidence is not so clear because the inclusions positioned in this region are less tensioned.

In global terms, it seems that the sequence of props releasing is not determinant in the behaviour of propped walls reinforced with geosynthetics.

6 CONCLUSIONS

The influence of the construction method in the behaviour of walls reinforced with geosynthetics is in the essential expressed as:

1. In a propped wall the horizontal displacements of the face and the strains in the inclusions located near the top of the wall are greater than in an incremental wall, being lesser the strains in the reinforcements positioned near the base of the structure.
2. The soil strains increase in the lower part of the wall when this is propped.
3. As face deformability of incremental walls is usually much higher than that of propped walls face, the construction method leads to small differences on the behaviour of the two types of walls near their tops, increasing that differences in the lower parts.
4. The sequence of props release seems to be relatively insignificant in the behaviour of propped walls reinforced with geosynthetics.

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